920MHz帯RFIDシステムにおける平面型伝送路とタグアンテナ研究

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Study on Planar Waveguide and Tag Antenna for 920MHz RFID System

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Radio frequency identification (RFID) reader antenna and RFID tag are the important parts in the RFID system, and the system performance is mainly affected by the capability of those two parts. In this study, a planar waveguide is used as a RFID reader antenna, which can confined the reading area of the RFID system. The performance of the reader antenna can be improved by eliminating the low sensitivity area and enhancing the energy efficiency. Using open and short terminations to replace the load termination can reduce the power loss, and the power reflection in the termination of the reader antenna can be used to enhance the average power level on it. A diode, which can electrically switch between open and short circuit, is used to terminate the waveguide. The numerical and experimental studies show that the proposed method can obtain the diversity gain to enhance the uniformity of the field distribution on the waveguide, and the proposed method applied to the smart-shelf system also shows the effectiveness. Moreover, the impedance matching between the RFID tag antenna and tag chip affects the performance the tag antenna, and the impedance of the tag antenna is easily affected by the other objects nearby. Therefore, the tag antenna designed to work in the high-order mode is proposed to reduce the influence of the environment on the input impedance of the tag antenna. The designed tag is fabricated, and the experimental results show that the tag working in the high-order mode has good performance when the tag attached to high dielectric and closely located objects.

1. Introduction

Radio frequency identification (RFID) is a wireless technique by using electromagnetic fields and has become more and more popular in recent years. RFID system has advantage of low-cost, free battery operation, non-line-of-sight, and long read range, and it has been widely used in automatic wireless identification. The most common application of the RFID system is object identification [1], and it also can be used in sensor network and power transmission. In the applications of the object identification, it can be applied to the access control for entrance guard system and the asset tracking for retailer [2]. In order to realize the full potential of RFID system, some key points should be discussed. In this study, enhancing the performance of the RFID system through improving the RFID reader antenna and RFID tag antenna is studied.

The planar waveguide is used as a RFID reader antenna in this study. The diversity reception, which is switching the termination condition of the planar waveguide to obtain the diversity gain, is proposed. Moreover, RFID tag is easily affected by the environment. In order to design the RFID tag that can be used for high dielectric and closely located objects, the tag antenna designed working in the high-order mode is proposed. Through the above-mentioned work, the performance of the RFID system can be improved.

2. Performance improvement of RFID reader antenna

RFID reader antenna is one of the most important components of the RFID system. It directly affects the performance of the RFID system. The microstrip line is a simple and effective way to achieve the near field communication. However, the near field RFID reader antenna using microstrip line has unintentional radiation, and the microstrip line usually uses the load termination to match the impedance, which absorbs the power. Therefore, a novel RFID reading approach is using a planar waveguide sheet as a RFID reader antenna which was proposed by Teijin Limited. The planar waveguide sheet shown in Fig. 1 can provide evanescent wave to communicate with RFID tags. Confinement of the detection region is a critical issue for RFID smart-shelf system. The detection region should be confined; otherwise, the tags which are not inside the desired detection region will be detected. In this study, a waveguide sheet is used as a reader antenna of the RFID smart-shelf system to communicate with the RFID tags and to confines the detection region.

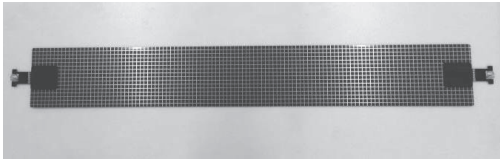

Fig. 1. Planar waveguide sheet used as a RFID reader antenna.

The waveguide sheet consists of a conducting mesh layer (top layer), dielectric substrate layer (middle layer) and a conducting ground plane (bottom layer). There are two ports in both sides of the planar waveguide sheet. The length and the width of the planar waveguide sheet are 800 and 110 mm, respectively. The mesh size of the top layer is 7 mm × 7 mm, and the width of the microstrip line of the mesh in top layer is 1 mm. The feeding component of the planar waveguide sheet is sandwiched by two conductive planes, and the inner and outer conductor of the coax are attached to each plane. There are two ports in each side of the planar waveguide sheet. Port 1 is the port connected to the RFID reader, and port 2 is terminated by a 50 Ohm load. Microwave for communication can propagate in the dielectric substrate layer and the conductive mesh layer forms an evanescent wave above the surface of the planar waveguide sheet. Therefore, the RFID tag antenna can receive the power by approaching the sheet.

In order to insure the feasibility of the planar waveguide sheet used as a RFID reader antenna, some experiments are presented. The measurement results of S11 shows that the S11 at 920 MHz is smaller than -15 dB, which demonstrated that the planar waveguide sheet can work as an antenna. The field distribution of the vertical direction on the sheet was measured and demonstrating that the load termination can reduce the refection from the end of the sheet and make the field distribution uniform. The detection region of the planar waveguide used as a RFID reader by using RFID tag DNP UL-21 was measured. It is indicated that the tag only can be detected when the tag close to the planar waveguide sheet. All results demonstrate that the planar waveguide sheet can work as a RFID reader antenna. However, when the tags attached to dielectrics, the dielectrics and the mutual coupling between tags affects the performance of the tags. The tags may have a chance of becoming undetectable. Moreover, the load used to terminate the planar waveguide sheet absorbs the energy and causes the power loss.

Therefore, the method of the diversity reception is proposed to obtain the diversity gain to improve the performance of the planar waveguide sheet used as a RFID reader antenna. In this study, open circuit and short circuit are used to terminate the planar waveguide sheet to obtain two different field distributions on the sheet, which are complementary to each other. The effectiveness of the diversity reception in electric field distribution is demonstrated by numerical analysis and experiments. Furthermore, in order to electrically switch the termination conditions between open and short circuit, the diodes are used to terminate the sheet. The experimental study is shown that the bias voltage of the diode switched between 0 and 1 V can also obtain different field distributions as shown in Fig. 2. The CDF of the field distribution are shown in Fig. 3, which indicated that the diode termination could provide 3.5 dB diversity gain at 1%. Finally, the other experiments are carried out to verify the improvement of the successful reading rate of tags and received signal strength indicator (RSSI) by using the diversity reception as shown in Fig. 4.

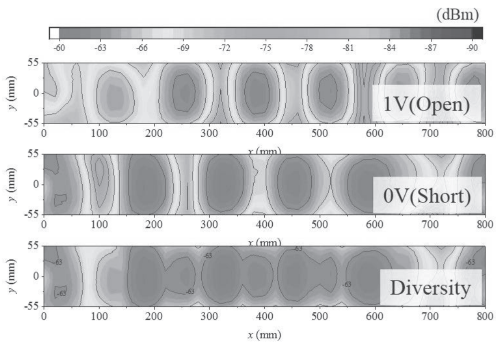

Fig. 2. Electric field distribution on waveguide with diode termination.

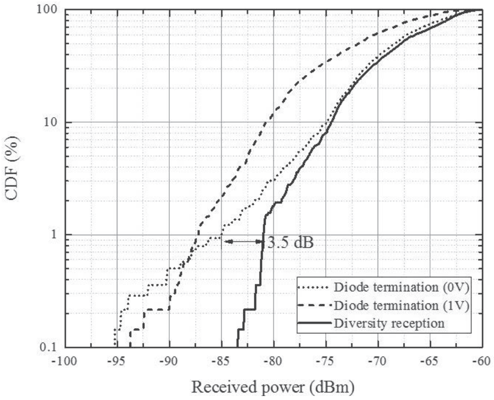

Fig. 3. CDF of electric field distribution by using proposed diversity reception

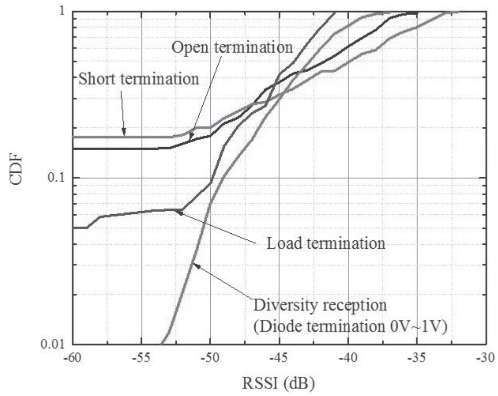

Fig. 4. CDF of proposed diversity reception applied to smart-shelf system.

3. RFID tag design for closely located and high dielectric objects

Ultra-high frequency (UHF) RFID tag is one of the most important components of affecting the RFID system performance. One of the key factors to make sure that the reader can obtain stable signals from the tag is to enhance the performance of the RFID tag. A passive RFID tag consists of a tag antenna and an Application Specific Integrated Circuit (ASIC) chip as shown in Fig. 5. To achieve the maximum power transmitting to the ASIC chip, the impedance of the tag antenna and the chip should be conjugate matched.

In the application of smart-shelf system, the RFID tag antenna is attached to the objects made of various materials. Different materials the objects have various

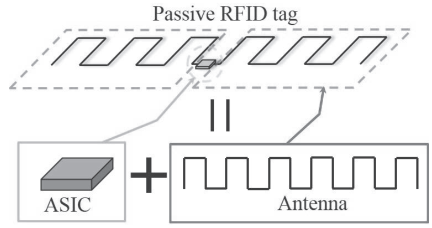

Fig. 5. Components of a passive UHF RFID tag

permittivity, and the effects on the tag antenna are different. For example, the relative permittivity of plastic is 2 to 3.5, the paper is 3.85, and the glass is 5 to 10. Some objects with high permittivity severely affect the performance of the tag antenna. In previous studies of the UHF RFID system, the RFID tags that are closely located on metals and dielectrics such as water or wood have been investigated.

In some applications, the managed objects are intensively located and the distance between two tags is very short. For example, the objects such as documents, books, and disks that are intensively located on a bookshelf. In those cases, the interference between two tags occurs when tags are closely located. Due to the interference of the objects nearby, the resonant frequency of the tag is changed, and the power input to the tag has a great chance to be decreased. For the conditions mentioned above, the research work should cover tag antenna design for working on surfaces of high dielectric objects and robust feature extraction for the interference from other tags nearby.

In this study, the effects of the dielectric objects and the other tag antenna nearby are presented. The tag antenna attached to a dielectric object affects the impedance of the tag antenna. The dielectric object makes the wavelength short, and the anti-resonant frequency of the tag antenna becomes lower. The higher the relative permittivity of the dielectric, the lower the anti-resonant frequency. When the other tag nearby, the impedance of the tag antenna is also affects, and the amplitude of impedance variation near the anti-resonant frequency becomes large. The shorter the separation distance, the larger the amplitude of the impedance variation. Based on the investigation results, a design method for the passive UHF RFID tag antenna was proposed. The working frequency of the tag antenna designed higher than the anti-resonant frequency can avoid the effects of the anti-resonant frequency when other objects nearby. However, the proposed method leads the antenna size becomes large, and the antenna is hard to be used in practical applications. Therefore, the tag antenna should be miniaturized. In this study, meandering the tag antenna is applied to enhance the electrical size of the tag antenna without enlarging the physical size.

The designed tag antenna by using proposed method is shown in Fig. 5. The tag antenna was fabricated and measured by using a RFID reader. Two experiments were carried out to verify the effectiveness of the proposed method. One was that two tags were put together with a small gap *d* between them to simulate the tags were attached to extremely thin objects, and the results are shown in Tab. 2. Tag A is a normal tag antenna and Tag B is the antenna designed by using proposed method. One was that the tag antennas were attached to four objects which had different permittivities to simulate different materials, and the results shows in Tab. 2.

The read range of the tag antenna can be defined as follow:

$$r = \frac{\lambda}{4\pi}\sqrt{\frac{P_t G_t G_r t}{P_a}}$$

,where P_t is the power transmitted by reader, G is antenna gain, t is the power transmission ration between tag antenna and tag chip ,and P_a is the minimum power to active chip. G, r, and P_a can be considered as constants, therefore, P_t can be used to evaluate the tag performance (the large the P_t, the better the tag performance.)

The experimental results showed that the tag antenna with larger electrical size has lower minimum active power than the small one when tags are attached to objects and intensively located objects. The result demonstrates that the designed electric large tag antenna has good performance when the other dielectric objects and other tags nearby.

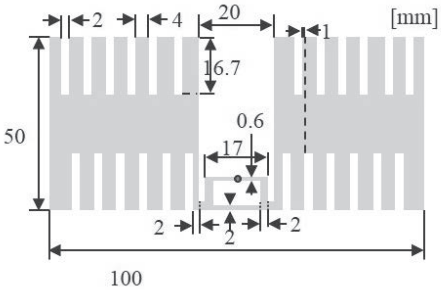

Fig. 5. Proposed RFID tag antenna.

Tab. 1 P_t for two tags with *d*.

d (mm)	Tag A-1	Tag A-2	Tag B-1	Tag B-2
2	18.25	18.75	17.25	**16.5**
5	18.75	18.75	18.25	**17.5**
10	20.75	20.75	19	**18.25**
20	20	20.5	19	**19**
50	19.25	19.75	19.25	19.25
100	**18.25**	18.5	19.5	19
One tag	**16.5**	17.25	19.75	19

Tab. 2. P_t for two tags attached to dielectrics.

ε_r	Tag A-1	Tag A-2	Tag B-1	Tag B-2
One tag	**16.5**	17.25	19.75	19
2.34	18.25	18.75	17.25	**16.5**
3.7×1	18.75	18.75	18.25	**17.5**
3.7×2	20.75	20.75	19	**18.25**
10	**16**	16.5	**16**	16.5

4. Conclusions

The performance of a RFID system can be enhanced by improving the RFID reader antenna and tag antenna. The planar waveguide sheet was used as a RFID reader antenna, and the diversity reception was proposed to enhance the power level of the electric field on the planar waveguide. The diode was used to switch the termination condition of the waveguide electrically. Numerical and experimental results showed the proposed method can obtain a diversity gain to improve the RFID system performance. Moreover, the RFID tag antenna designed to work in the high-order mode was proposed. The designed tag by using proposed method showed was fabricated, and the experimental results showed the designed tag has good performance when the tag attached to the high dielectric and closely located objects.

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